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Sanderson et al.

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(54) **FRICTION DAMPING MECHANISM FOR DAMPED BEAMS AND OTHER STRUCTURES**

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(51) **Int. Cl.**

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F16F 7/10	(2006.01)
E01D 19/04	(2006.01)
E01D 19/00	(2006.01)
F16F 7/00	(2006.01)
E04B 1/98	(2006.01)

(52) **U.S. Cl.**

CPC ***E04H 9/023*** (2013.01); ***E01D 19/00*** (2013.01); ***E01D 19/043*** (2013.01); ***E04H 9/027*** (2013.01); ***F16F 7/00*** (2013.01); ***F16F 7/1022*** (2013.01); *E04B 1/985* (2013.01)

(58) **Field of Classification Search**

CPC E04H 9/027; E04H 9/023; E04H 9/029; E04B 1/985; F16F 7/1022; F16F 7/00

USPC 52/167.9, 167.5, 167.4, 167.1, 167.8; 248/560, 562, 563, 566, 568; 384/36, 384/44–46, 99, 101, 491–492, 513, 565, 384/261; 188/381, 378, 379, 380; 267/205, 267/41, 182

See application file for complete search history.

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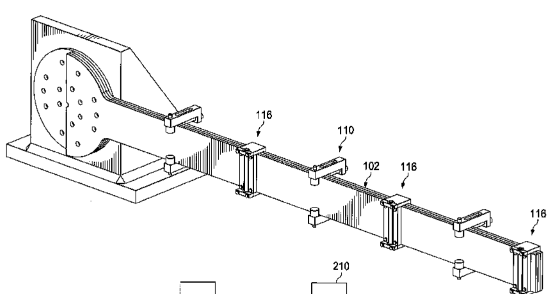
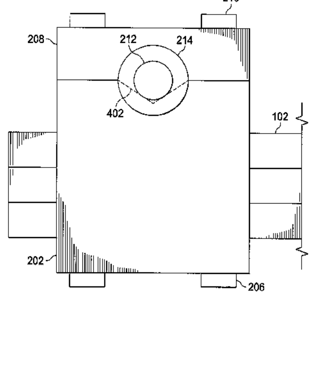
(57) **ABSTRACT**

A system includes a structure configured to undergo oscillatory movement. The system also includes a friction damping clamp coupled to the structure. The friction damping clamp includes a housing having a groove. The friction damping clamp also includes a roller positioned at least partially within the groove, where the groove has first and second ramps. The roller is configured to move up each ramp of the groove so that more compression is applied on the structure and to move down each ramp of the groove so that less compression is applied on the structure. The roller may be configured to apply more compression on the structure to increase friction between portions of the structure, to apply less compression on the structure to decrease friction between the portions of the structure, and to apply substantially no compression on the structure when the roller is located at a center of the groove.

20 Claims, 14 Drawing Sheets





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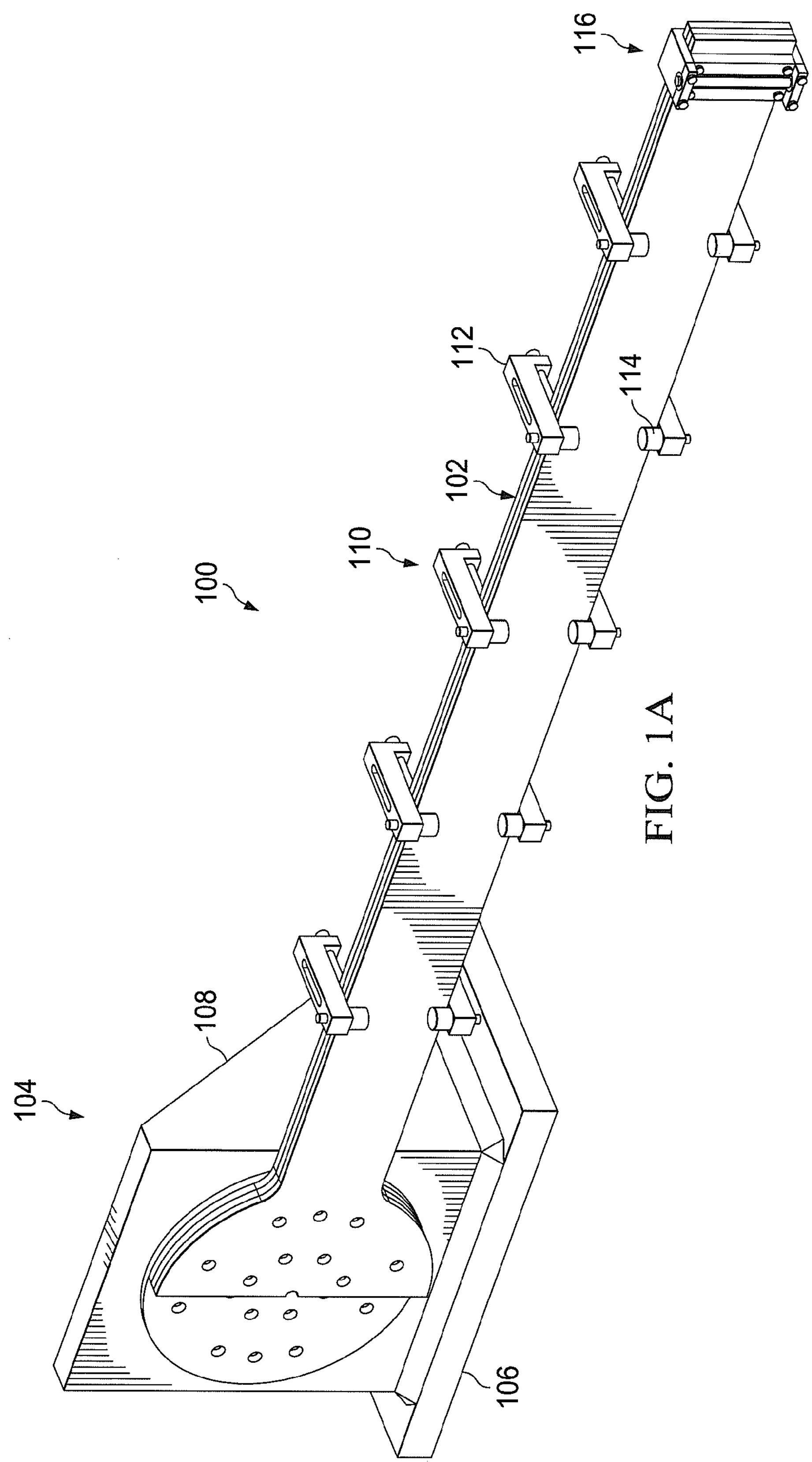

FIG. 1A

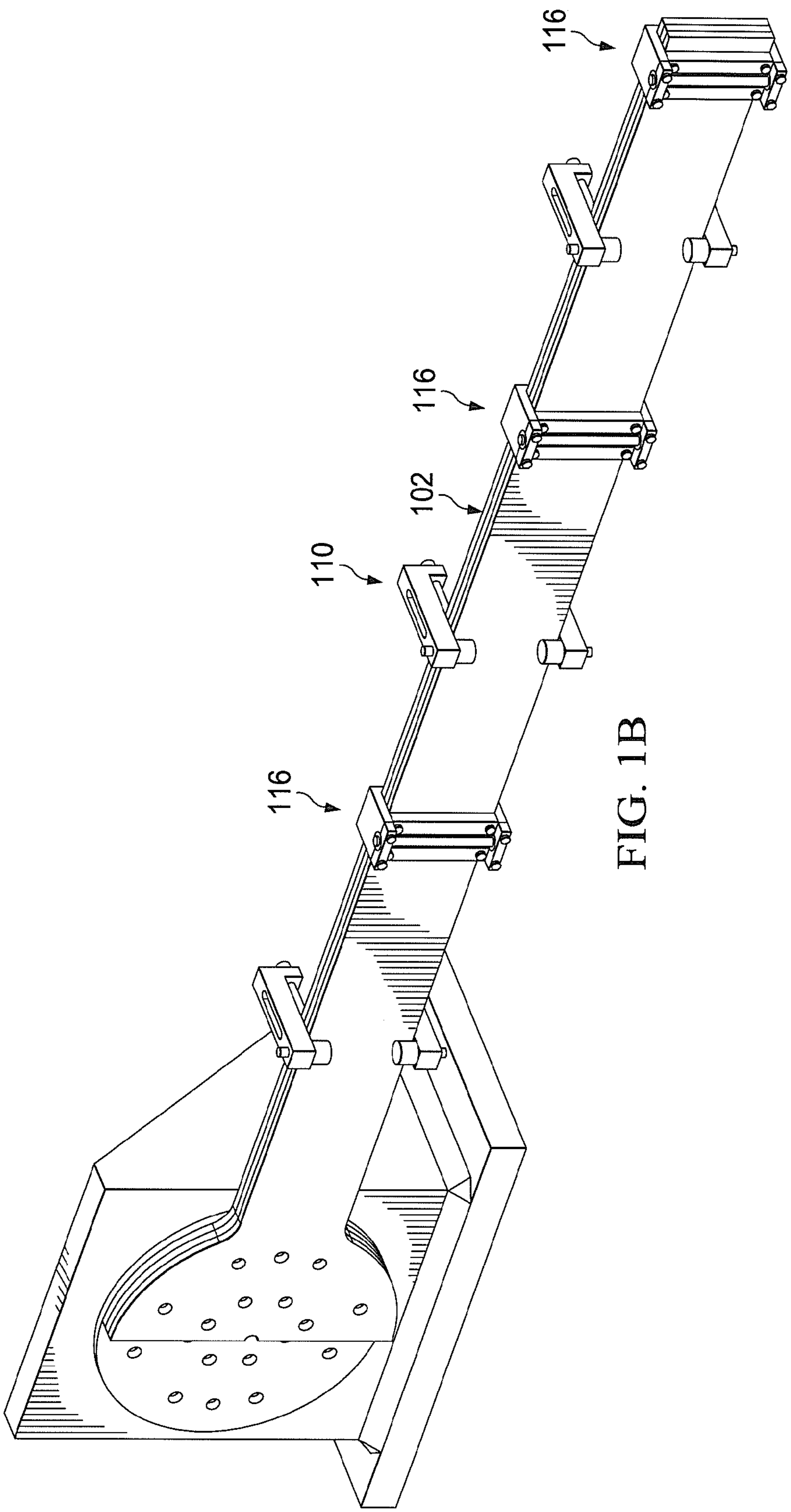

FIG. 1B

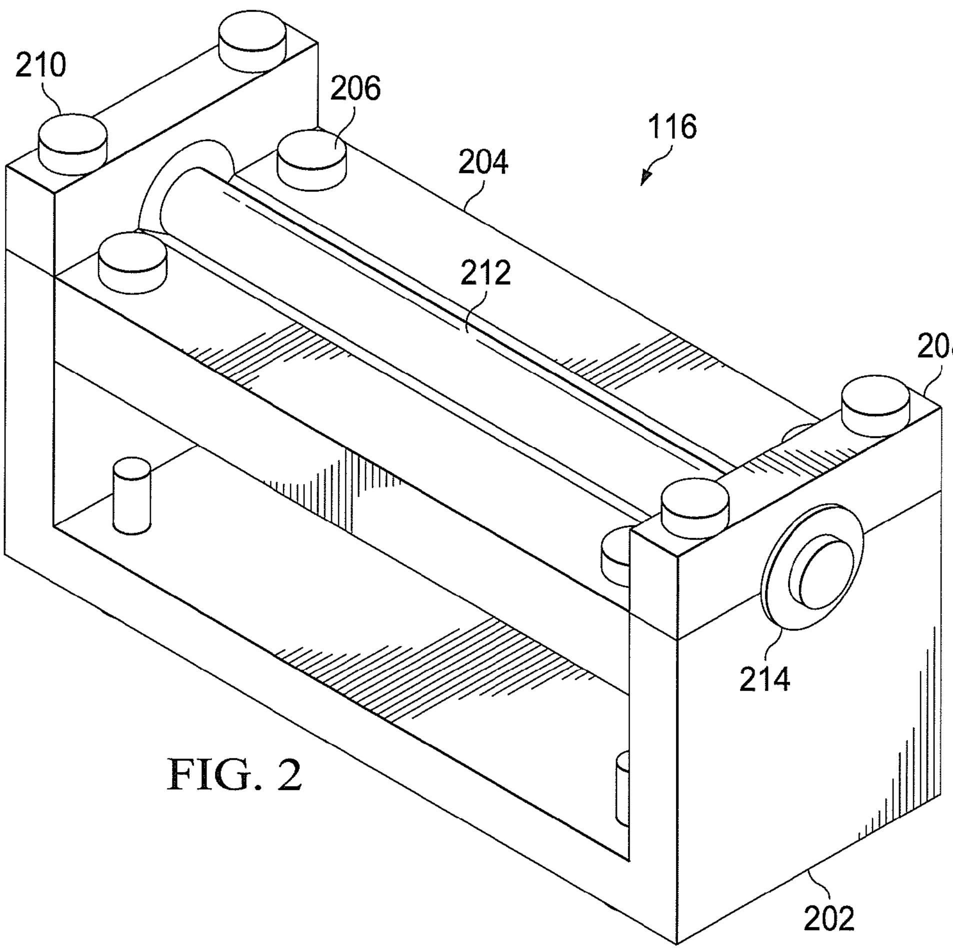

FIG. 2

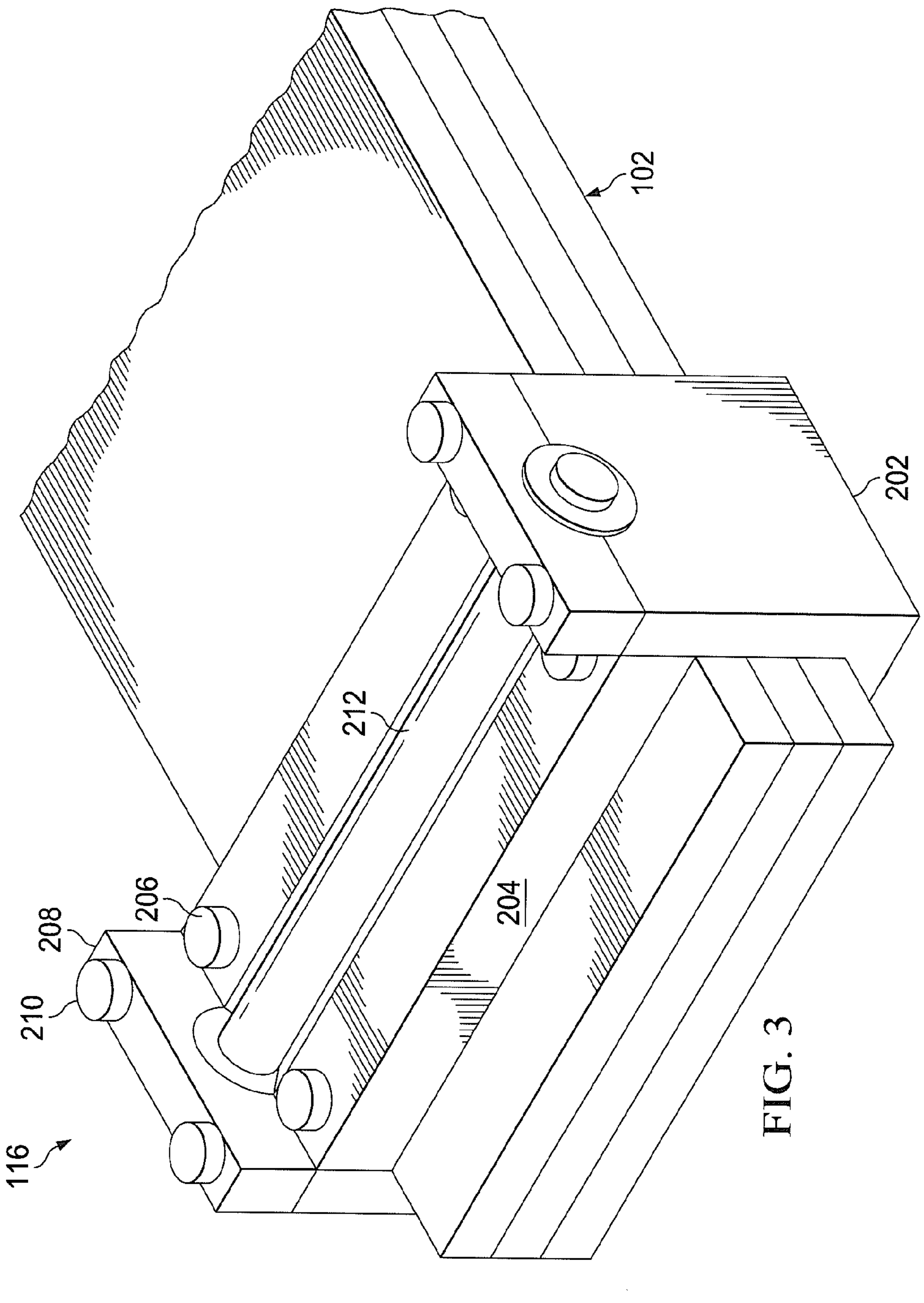

FIG. 3

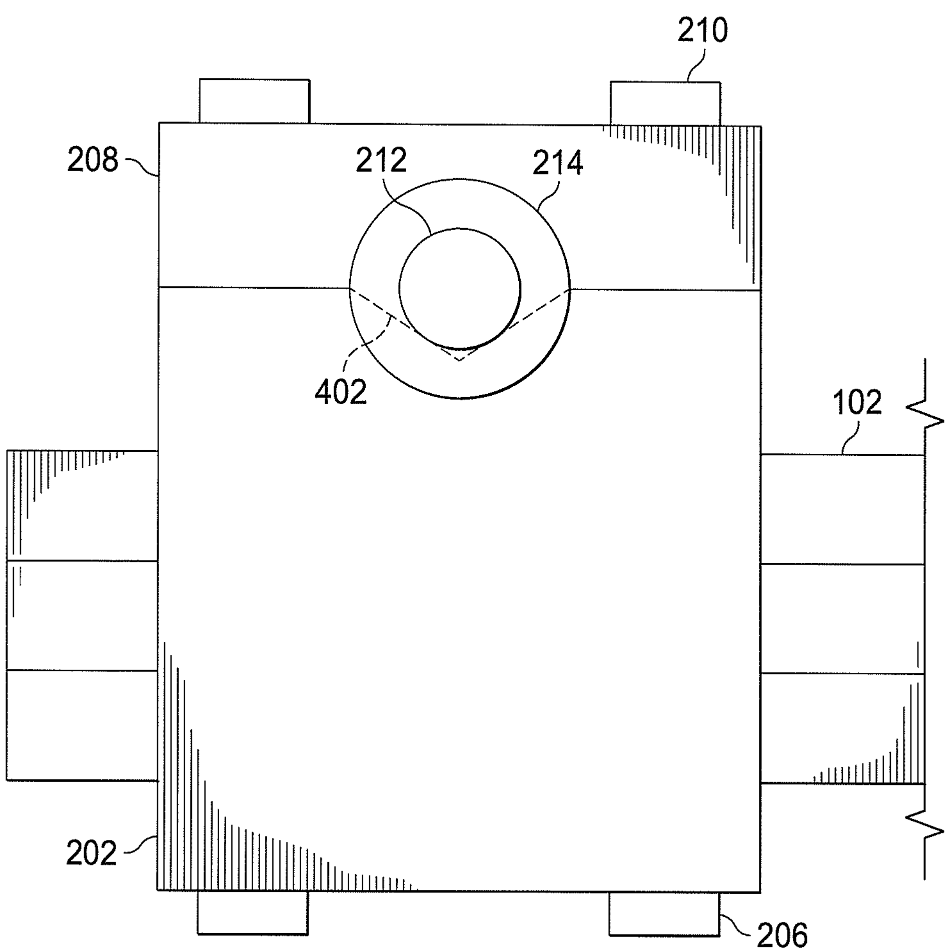

FIG. 4A

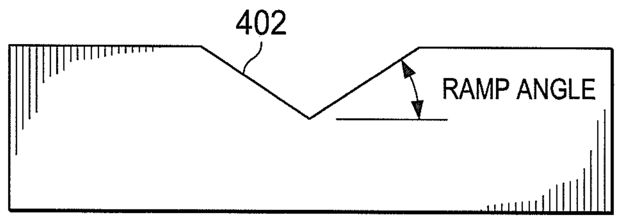

FIG. 4B

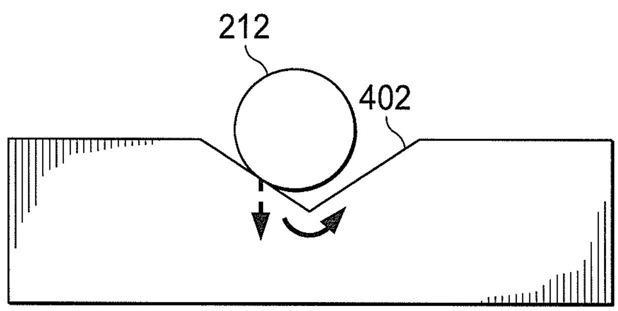

FIG. 5A

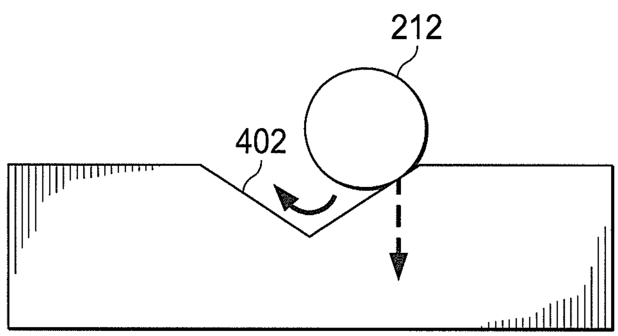

FIG. 5B

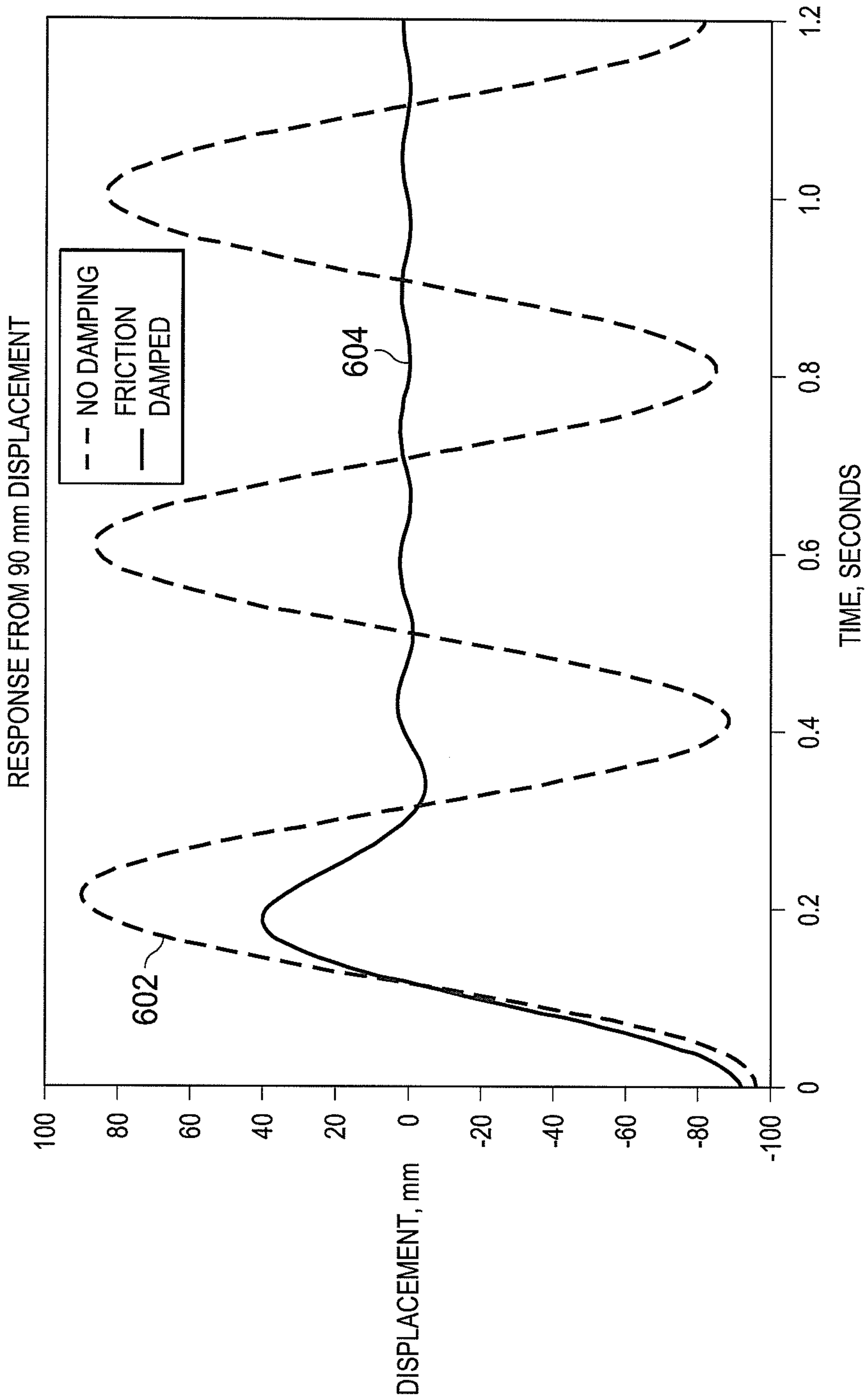
RESPONSE FROM 90 mm DISPLACEMENT
NO DAMPING
FRICTION
DAMPED
602
604
DISPLACEMENT, mm
100
80
60
40
20
0
-20
-40
-60
-80
-100
TIME, SECONDS
0
0.2
0.4
0.6
0.8
1.0
1.2

FIG. 6

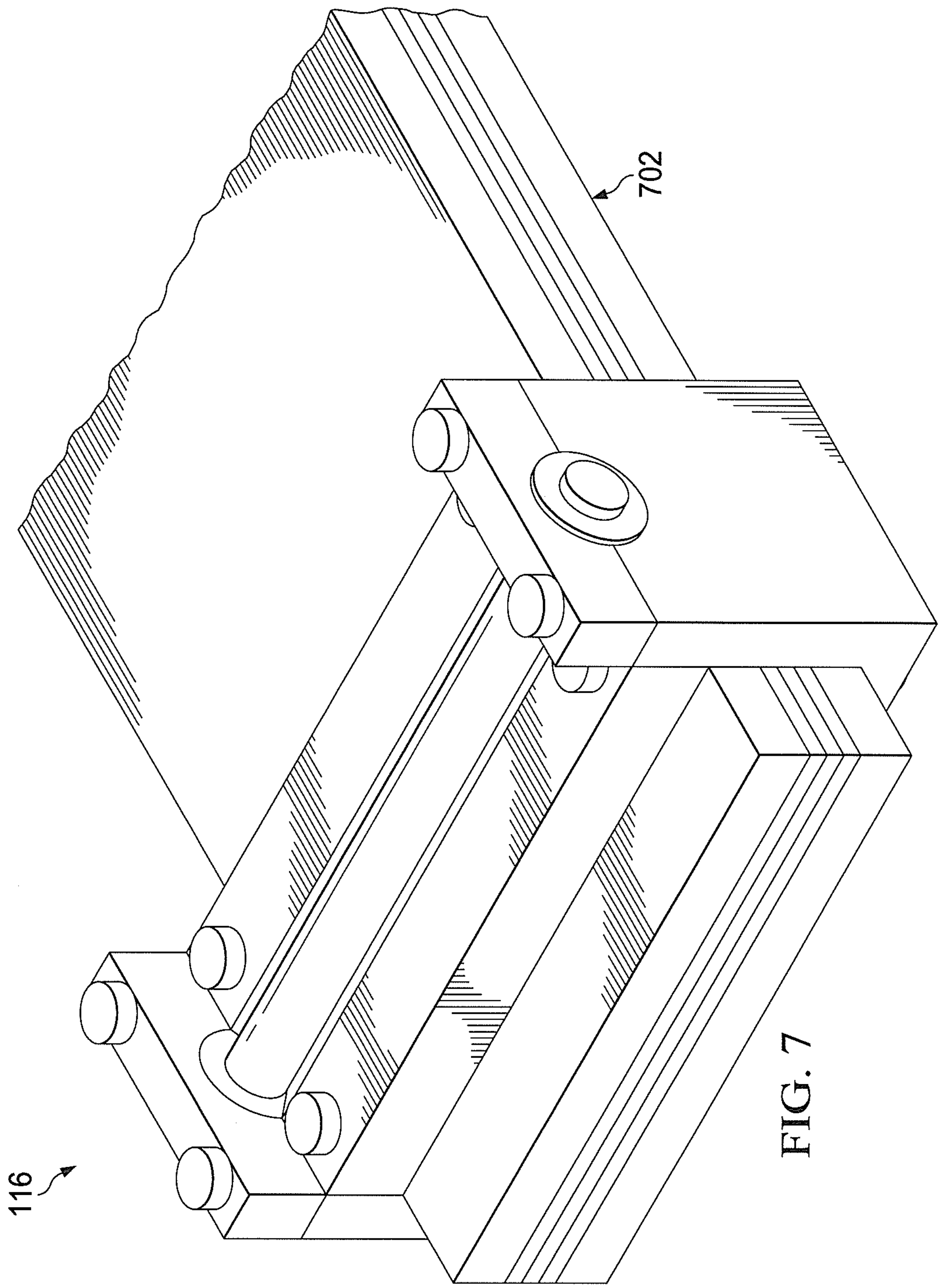

FIG. 7

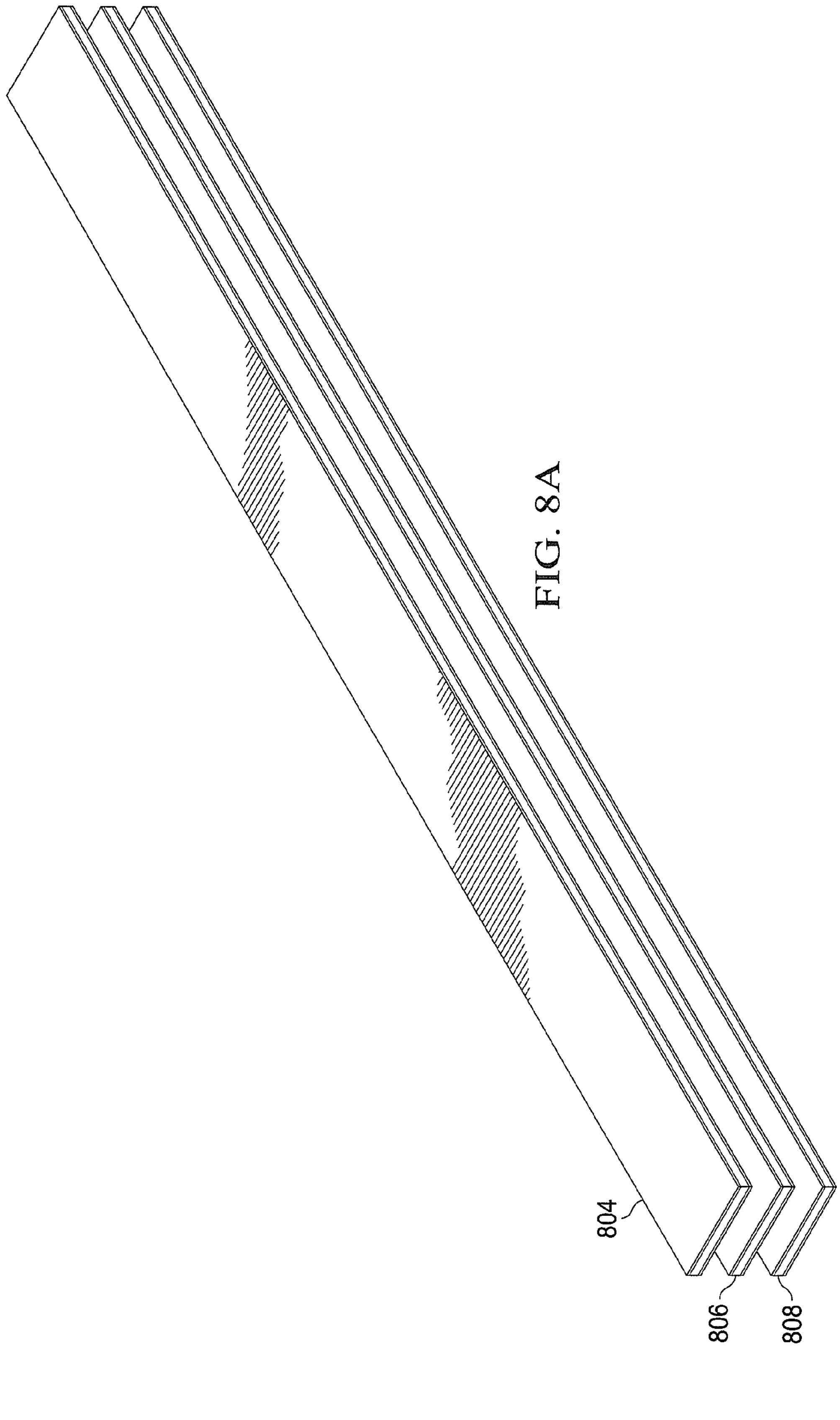

FIG. 8A

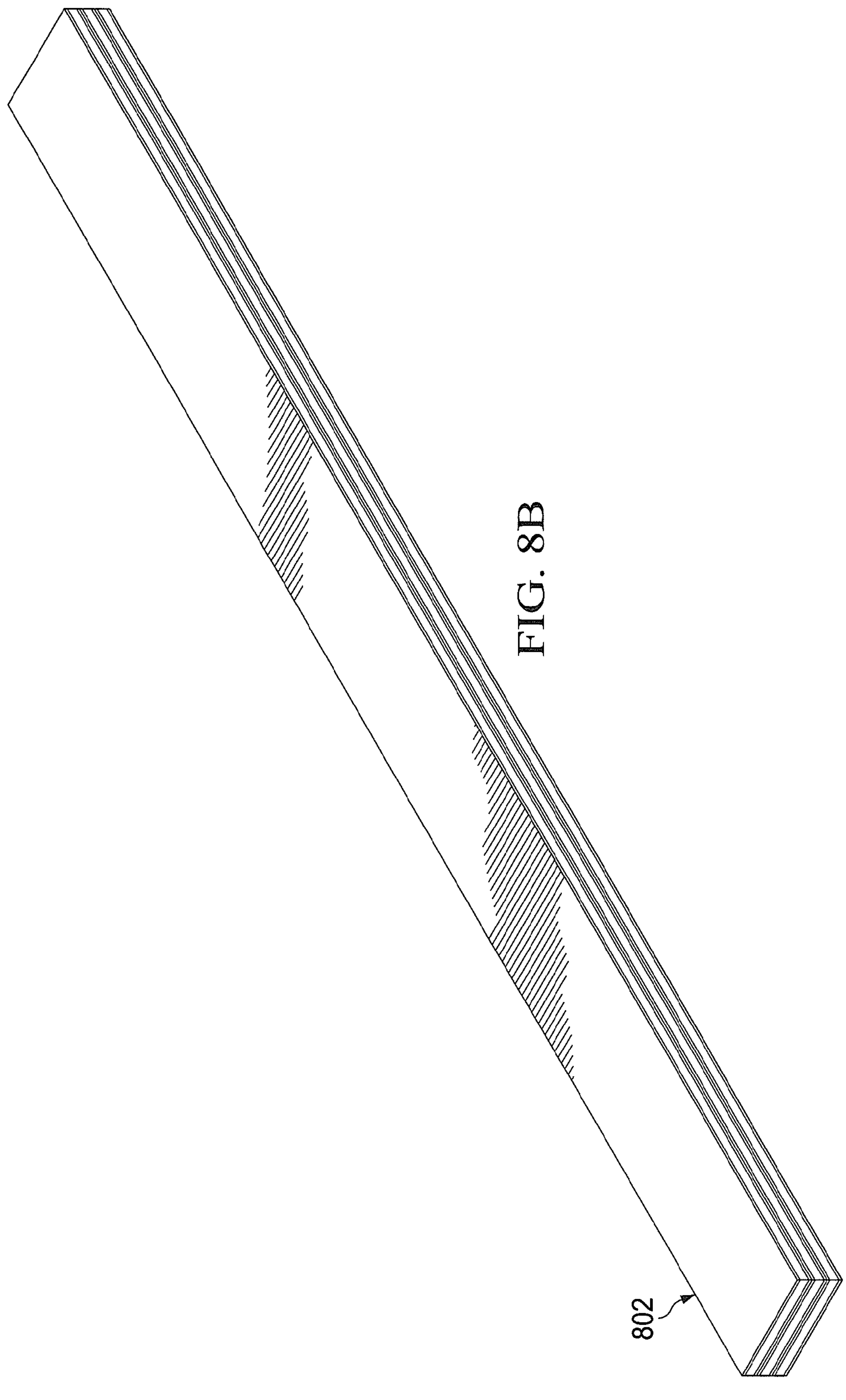

FIG. 8B

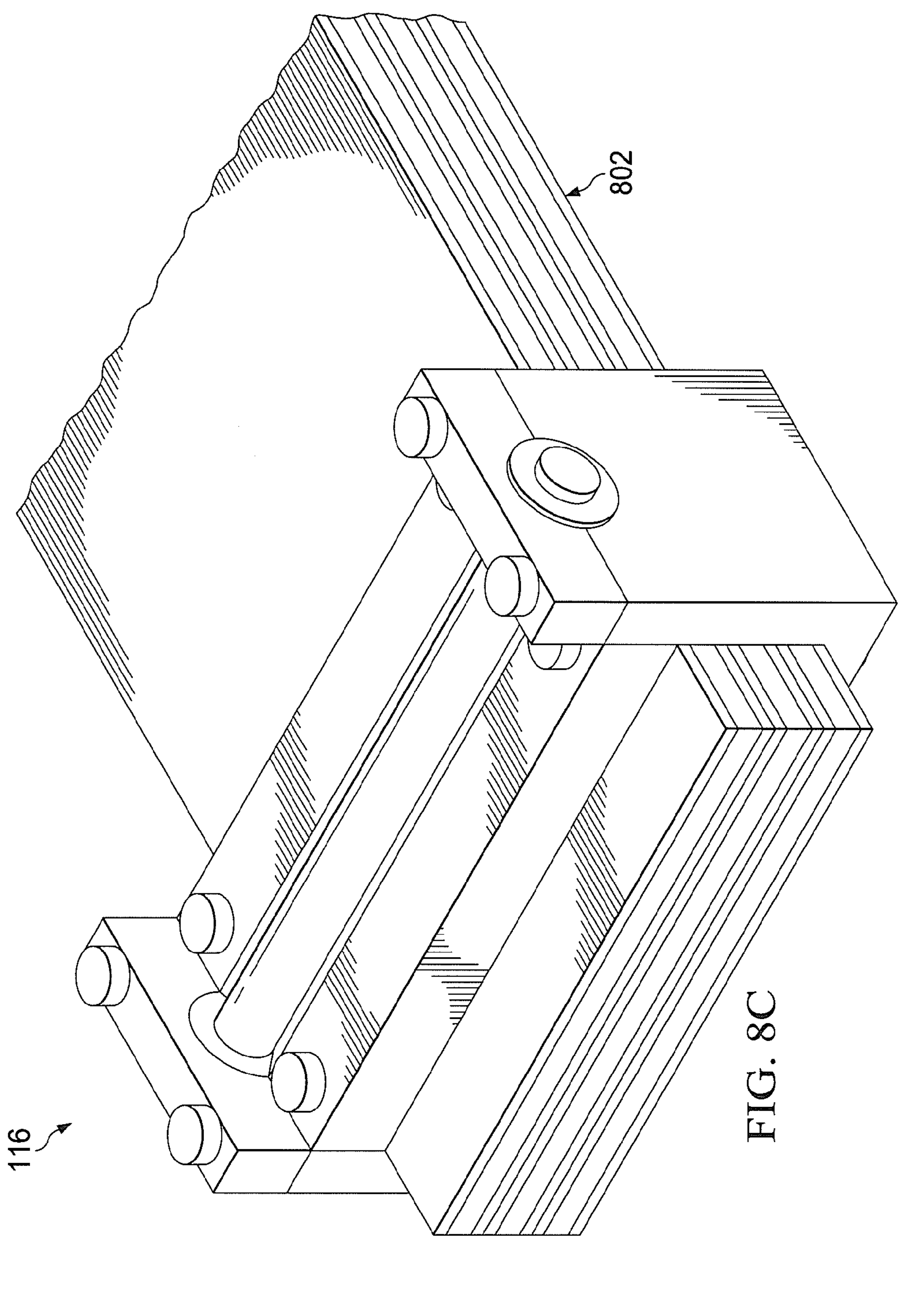

FIG. 8C

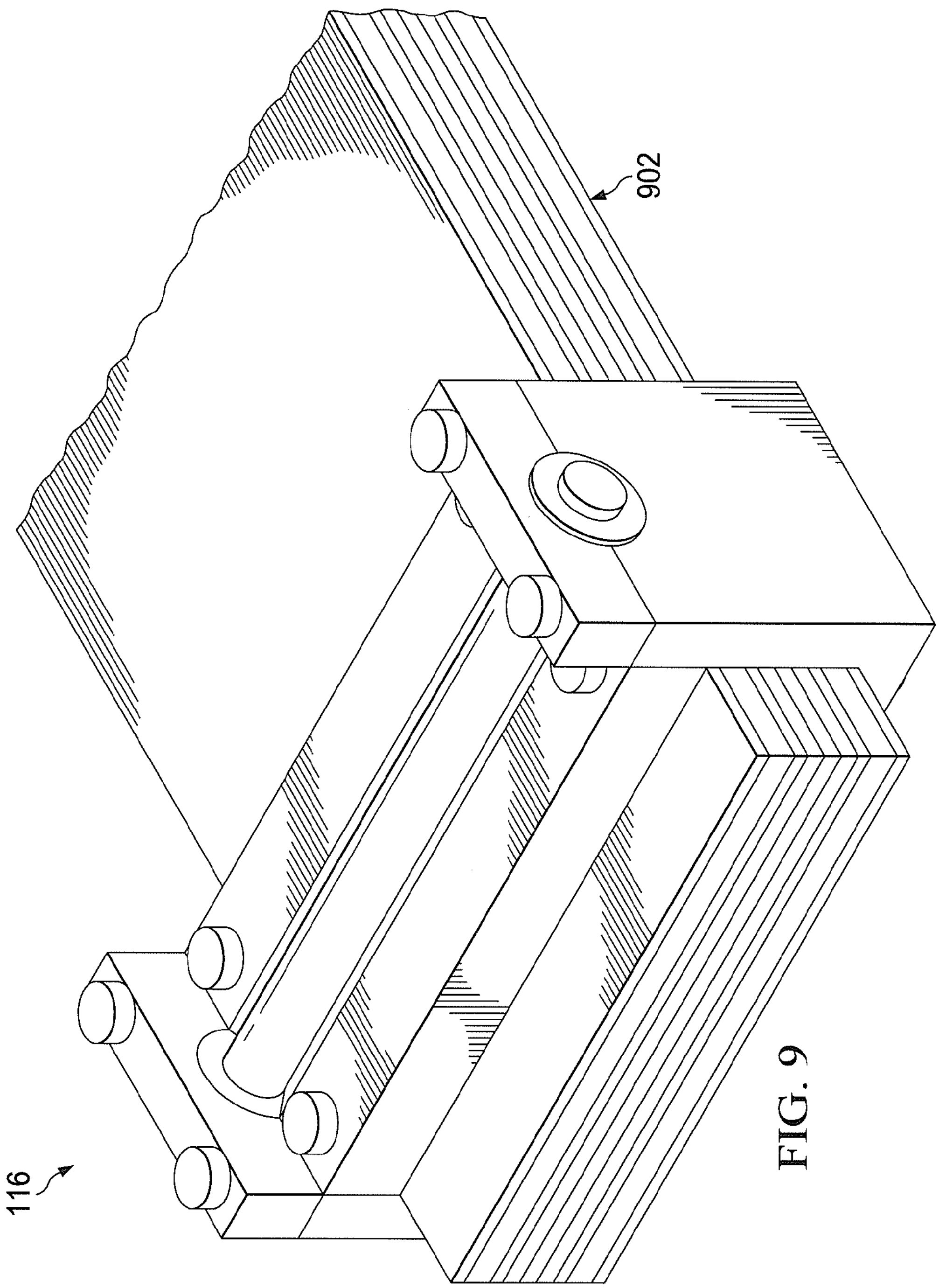

FIG. 9

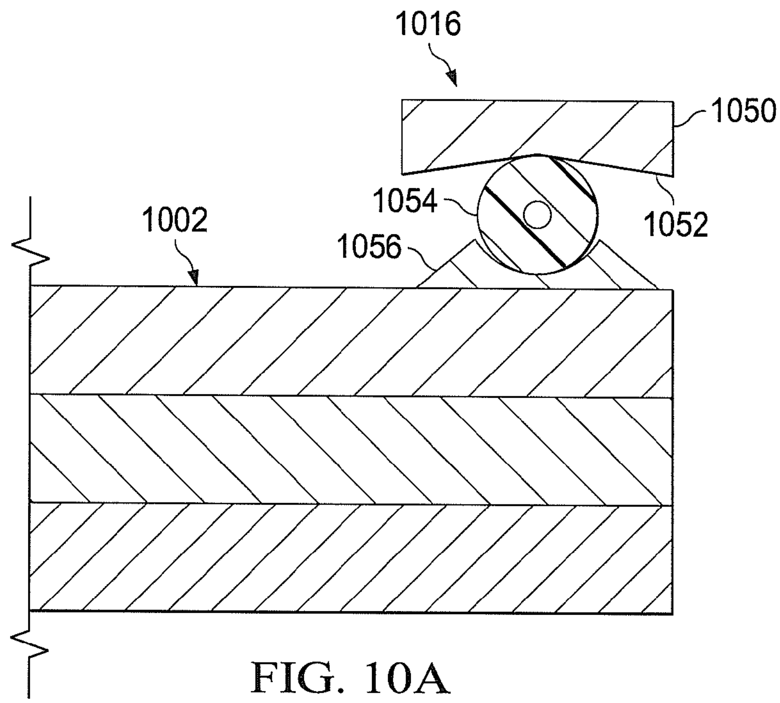

FIG. 10A

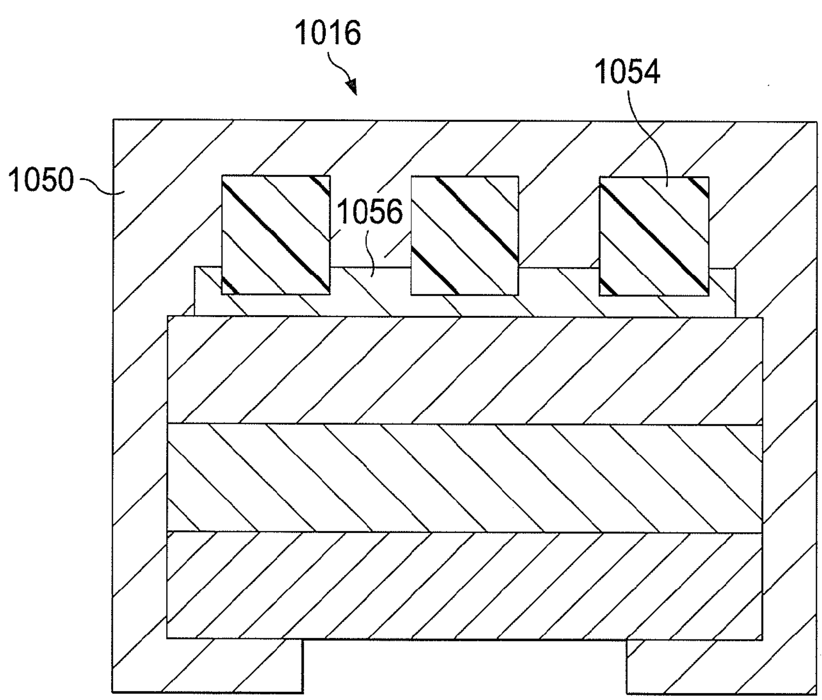

FIG. 10B

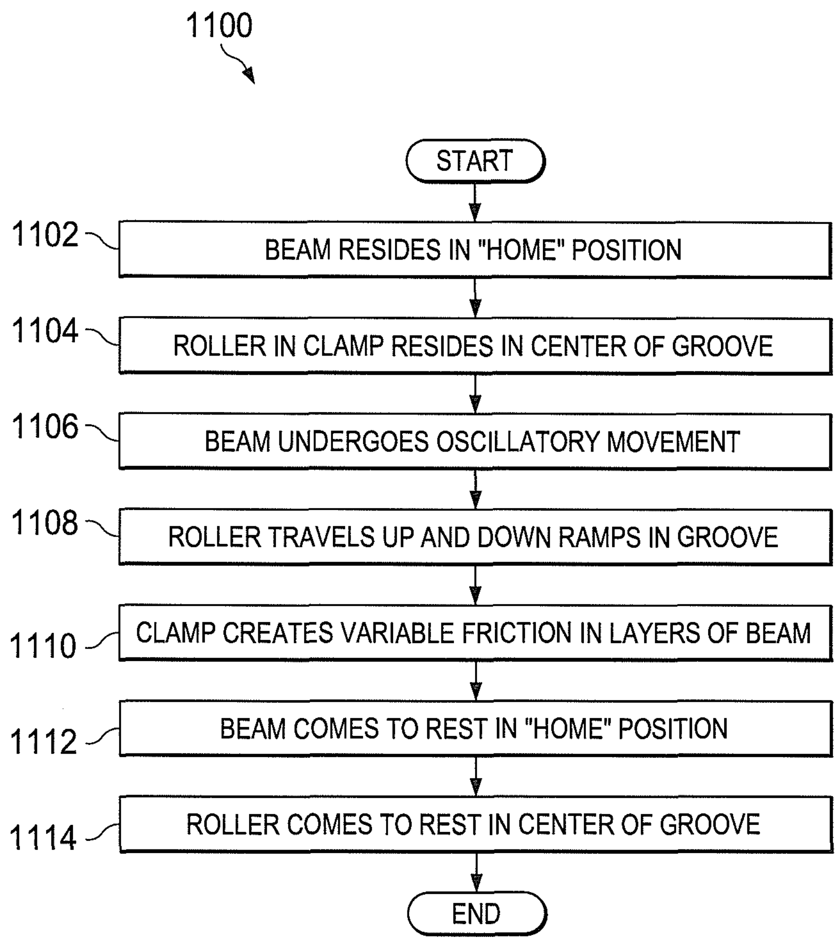
1100
START
1102
BEAM RESIDES IN "HOME" POSITION
1104
ROLLER IN CLAMP RESIDES IN CENTER OF GROOVE
1106
BEAM UNDERGOES OSCILLATORY MOVEMENT
1108
ROLLER TRAVELS UP AND DOWN RAMPS IN GROOVE
1110
CLAMP CREATES VARIABLE FRICTION IN LAYERS OF BEAM
1112
BEAM COMES TO REST IN "HOME" POSITION
1114
ROLLER COMES TO REST IN CENTER OF GROOVE
END

FIG. 11

FRICTION DAMPING MECHANISM FOR DAMPED BEAMS AND OTHER STRUCTURES

GOVERNMENT LICENSE RIGHTS

This invention was made with U.S. government support under Contract No. HR0011-11-C-0069 awarded by the Defense Advanced Research Projects Agency (DARPA). The U.S. government may have certain rights in the invention.

TECHNICAL FIELD

This disclosure is generally directed to damping mechanisms. More specifically, this disclosure relates to a friction damping mechanism for damped beams and other structures.

BACKGROUND

Damping refers to the action of reducing back-and-forth oscillations of a structure until it comes to rest. Many types of structures could benefit from high levels of damping. Some damping solutions involve the use of viscous or elastomeric devices, such as dashpots and elastomeric isolators. However, these devices are typically bulky and add considerable weight to the overall structure. Other damping solutions involve the use of friction dampers with beams formed from multiple layers that can slip against each other. Unfortunately, these "split beam" friction dampers typically result in permanent offset after excitation, meaning a beam cannot return to its beginning or "home" position after oscillatory movement is incited. Moreover, conventional "split beam" friction dampers can typically access only a fraction of the total damping power that is contained within a beam.

SUMMARY

This disclosure provides a friction damping mechanism for damped beams and other structures.

In a first embodiment, a system includes a structure configured to undergo oscillatory movement. The system also includes a friction damping clamp coupled to the structure. The friction damping clamp includes a housing having a groove. The friction damping clamp also includes a roller positioned at least partially within the groove, where the groove has first and second ramps. The roller is configured to move up each ramp of the groove so that more compression is applied on the structure, and the roller is configured to move down each ramp of the groove so that less compression is applied on the structure.

In a second embodiment, an apparatus includes a friction damping clamp configured to be coupled to a structure that undergoes oscillatory movement. The friction damping clamp includes a housing having a groove. The friction damping clamp also includes a roller positioned at least partially within the groove, where the groove has first and second ramps. The roller is configured to move up each ramp of the groove so that more compression is applied on the structure. The roller is also configured to move down each ramp of the groove so that less compression is applied on the structure.

In a third embodiment, a method includes creating oscillatory movement of a structure and damping the oscillatory movement using a friction damping clamp coupled to the structure. The friction damping clamp includes a housing having a groove. The friction damping clamp also includes a roller positioned at least partially within the groove, where the groove has first and second ramps. Damping the oscillatory movement includes moving the roller up each ramp of the groove to apply more compression on the structure and moving the roller down each ramp of the groove to apply less compression on the structure.

Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this disclosure and its features, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIGS. **1**A and **1**B illustrate example structures with friction damping mechanisms in accordance with this disclosure;

FIGS. **2** through **6** illustrate an example friction damping mechanism and related details in accordance with this disclosure;

FIGS. **7** through **9** illustrate additional structures with friction damping mechanisms in accordance with this disclosure;

FIGS. **10**A and **10**B illustrate another example friction damping mechanism in accordance with this disclosure; and

FIG. **11** illustrates an example method of using a friction damping mechanism in accordance with this disclosure.

DETAILED DESCRIPTION

FIGS. **1**A through **11**, described below, and the various embodiments used to describe the principles of the present invention in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the invention. Those skilled in the art will understand that the principles of the present invention may be implemented in any type of suitably arranged device or system.

FIGS. **1**A and **1**B illustrate example structures with friction damping mechanisms in accordance with this disclosure. As shown in FIG. **1**A, a structure **100** includes a beam **102** that is secured to a support structure **104**. The beam **102** generally represents a narrower structure that is supported at one or more points by other structures. In this example, the beam **102** represents a cantilevered beam, meaning the beam **102** is supported at one end but not at the other end. However, other types of beams could also be used here, such as a fixed beam supported at both ends by support structures.

The beam **102** could be formed from any suitable material(s) and in any suitable manner. Here, the beam **102** represents a multi-layer or "split beam" structure that is formed from multiple layers of material(s), where at least one layer of the beam **102** slips with respect to at least one other layer of the beam **102**. This creates one or more slip/friction planes in the beam **102**, which help to dampen oscillations of the beam **102**. Each layer of the beam **102** could be formed from any suitable material(s), such as stainless steel or aluminum.

The support structure **104** generally represents any suitable structure on which the beam **102** can be mounted or otherwise supported. In this example, the support structure **104** includes a base **106** and a wedge-shaped upper portion **108**, where the beam **102** is coupled to a raised surface on the upper portion **108**. The support structure **104** could have any other suitable size and shape. Also, the support structure **104** could be formed from any suitable material(s) and in any suitable manner. In addition, any suitable coupler(s) or other mechanisms could be used to secure the beam **102** to the support structure **104**, such as bolts. In particular embodiments such as a small airplane or missile, the beam **102** could represent a wing, and the support structure **104** could represent the fuselage or center support of an airframe.

As shown in FIG. **1**A, multiple anti-buckling rollers **110** are positioned along the span of the beam **102**. The anti-buckling rollers **110** generally operate to prevent buckling of the beam **102**, which helps to prevent shear energy in the beam **102** from converting into buckling energy. In this example, each anti-buckling roller **110** includes a roller support **112**, which is coupled to one layer of the beam **102**. Each roller support **112** is coupled to a movable roller **114**, which helps to restrain movement of the beam **102**. Each roller support **112** could be formed from any suitable material(s) (such as stainless steel or aluminum) and in any suitable manner. Each roller **114** could also be formed from any suitable material(s) and in any suitable manner.

The beam **102** further includes a friction damping clamp **116**. The clamp **116** is secured to the beam **102** and generally operates to help dampen oscillations of the beam **102**. The clamp **116** does this by applying variable levels of compression to the beam **102**, which affects the amount of friction between the various layers of the beam **102**. By allowing control of friction normal forces in various profiles, the damping provided by the clamp **116** can be tuned to utilize shear energy available in the beam **102** to a larger or maximal extent. Unlike conventional approaches, the clamp **116** allows the beam **102** to return substantially to a beginning or "home" position after oscillatory movement begins and is suppressed. This can reduce or eliminate the permanent offset typically present in conventional approaches. Moreover, the clamp **116** is designed to access a significantly larger fraction of the total damping power that is contained within the beam **102** compared to conventional approaches (and possibly allows access to all damping power of the beam **102**). Additional details of the design and operation of the clamp **116** are provided below.

The friction damping clamp **116** is used in FIG. **1**A near the end of the beam **102**. However, at least one clamp **116** could be used in one or more other or additional locations along the beam **102**. For example, the beam **102** could have any number of clamps **116**, such as multiple clamps **116** distributed evenly or unevenly along the length of the beam **102**. As a particular example, one or more anti-buckling rollers **110** could be replaced by one or more clamps **116**. An example of this is shown in FIG. **1**B, where several anti-buckling rollers **110** have been replaced with friction damping clamps **116**. The remaining anti-buckling rollers **110** could also be omitted or similarly replaced with friction damping clamps **116**.

Note that materials having higher coefficients of friction could be used in the beam **102** to dampen oscillations with less clamping power required from the friction damping clamp **116**. Alternatively, materials having lower coefficients of friction could be used in the beam **102** to dampen oscillations with more clamping power required from the friction damping clamp **116**. This provides great flexibility in both the selection of materials for the beam **102** and the design of the clamp **116**.

Also note that any suitable structure could use one or more friction damping clamps **116** to reduce oscillatory movement, such as structures in buildings, bridges, vehicles, aircraft, and ships. As particular uses, the friction damping clamp **116** could find use in vehicle and ship shock absorbing systems, structural components within highly accurate mechanisms, and inertial measurement unit (IMU) isolation structures.

Although FIGS. **1**A and **1**B illustrate examples of structures with friction damping mechanisms, various changes may be made to FIGS. **1**A and **1**B. For example, the relative sizes, shapes, and dimensions of the components in FIGS. **1**A and **1**B are for illustration only. Also, any suitable structure can use at least one friction damping clamp **116**, and any number of friction damping clamps **116** could be used with that structure.

FIGS. **2** through **6** illustrate an example friction damping mechanism and related details in accordance with this disclosure. In particular, FIGS. **2** through **6** illustrate details of an example friction damping clamp **116**. As shown in FIGS. **2** through **4**, the clamp **116** includes a housing, which is formed by a lower housing member **202** and an upper housing member **204**. The housing members **202-204** generally encircle the beam **102**, which fits within an opening between the housing members **202-204**. The housing members **202-204** are also secured to different layers of the beam **102** using connectors **206**. Note, however, that the housing need not completely encircle the beam **102**.

In this example, the lower housing member **202** extends across a bottom of the beam **102** and up the sides of the beam **102**, and the upper housing member **204** fits between the upwardly-projecting sides of the lower housing member **202**. However, the upper housing member **204** is not fixed to the lower housing member **202**, allowing the upper housing member **204** to move closer to or farther away from the bottom of the lower housing member **202**. This allows the upper housing member **204** to apply different amounts of compression to the beam **102**, thereby altering the amount of friction generated between the layers of the beam **102**.

Each housing member **202-204** could be formed from any suitable material(s), such as stainless steel or aluminum. Each housing member **202-204** could also be formed in any suitable manner, such as by machining or molding. Each connector **206** includes any suitable structure for coupling (either temporarily or permanently) two or more other structures together, such as bolts.

The lower housing member **202** here is coupled to multiple retainers **208**, which are coupled to the lower housing member **202** using connectors **210**. Each retainer **208** could be formed from any suitable material(s) (such as stainless steel or aluminum) and in any suitable manner (such as by machining or molding). Each connector **210** includes any suitable structure for coupling (either temporarily or permanently) two or more other structures together, such as bolts.

The lower housing member **202** and the retainers **208** define openings used to secure at least one roller **212** and its associated bearings **214**. In this example, a single roller **212** extends completely across the beam **102**, and the ends of the roller **212** with the bearings **214** are secured between the lower housing member **202** and the retainers **208**. As shown in FIGS. **1**A and **1**B, multiple rollers could also be used in place of the single roller **212**. Each roller **212** could be formed from any suitable material(s) and in any suitable manner. The bearings **214** could also be formed from any suitable material(s) and in any suitable manner.

As shown in FIGS. **4**A and **4**B, the upper surface of the housing member **204** includes at least one groove **402**. The groove **402** here is V-shaped, meaning a groove with substantially straight sides. At least a portion of each roller **212** fits within an associated groove **402**. During movement of the beam **102**, each roller **212** can move up and down over the slanted ramp surfaces of the groove **402**. This creates a varying amount of friction in the beam **102**. For example, the roller **212** forces the upper housing member **204** down against the beam **102** more when the roller **212** is higher up the groove **402**, creating greater friction between the layers of the beam **102**. The roller **212** forces the upper housing member **204** down against the beam **102** less when the roller **212** is lower up the groove **402**, creating lesser friction between the layers of the beam **102**. The roller **212** may not force the upper housing member **204** down against the beam **102** at all when the roller **212** is centered in the groove **402**, creating a minimal amount of friction between the layers of the beam **102**.

This allows the layers of the beam **102** to slip with respect to one another, but the amount of friction between the layers varies. This helps to more quickly dampen oscillatory movement of the beam **102**. For example, if the free end of the beam **102** opposite the support structure **104** in FIGS. **1**A and **1**B is moved in one direction and released, the free end of the beam **102** swings back and forth. This causes the roller(s) **212** to roll up and down one side of the groove(s) **402** and then up and down the other side of the groove(s) **402**. This can be repeated any number of times until each roller **212** comes to rest at the bottom of its groove **402**, at which point the beam **102** is no longer oscillating.

In this example, the friction force within the beam **102** varies linearly with displacement. That is, when there is no displacement of the beam **102**, each roller **212** can be located at the center of its groove **402**, at which point there is little or no friction created by that roller **212**. Displacement in either direction causes each roller **212** to roll up one side of its groove **402**, increasing the friction experienced between the layers of the beam **102**. Higher movements up the side(s) of the groove(s) **402** create larger amounts of friction, while smaller movements up the side(s) of the groove(s) **402** create smaller amounts of friction.

In this way, the clamp **116** creates variable friction that increases with displacement of the beam's layers, helping to more rapidly stop oscillatory movement of the beam **102**. Moreover, there is no or substantially no friction present when each roller **212** is located in the center of its groove **402**, so each roller **212** can return to substantially the same position (the "home" position) after each displacement of the beam **102**. This can eliminate permanent offset of the beam's position, which is common in conventional solutions. In addition, the bolts **206** used to secure the upper housing member **204** to the beam **102** could be adjustable, allowing the upper housing member **204** to reside a desired distance above the beam **102**. This allows for the tuning of the friction force applied to the beam **102**.

The materials used to form the various components of the clamp **116** could vary depending on the application. For example, various components could be formed from materials selected for friction consistency and wear resistance based on given or expected loading conditions in a particular application. Also, the clamp **116** could be designed to have a desired overall stiffness, such as a stiffness based on the inverted beam-to-clamp cross sectional area ratio. In some embodiments, the clamp **116** is approximately ten times stiffer than the beam **102**.

Moreover, the ramp angle of the groove **402** (defined as shown in FIG. **4**B) could be optimized based on the expected shear stress in the beam **102**. Under classical beam theory, the available shear flow q of a beam can be defined as:

$$q = \frac{6F_e}{h^3}\left[\left(\frac{h}{2}\right)^2 - y_1^2\right]$$

where F_e denotes the applied beam tip load, h denotes the beam's height (the overall thickness of its layers), and y_1 denotes distance from the beam's neutral axis to the centroid of the section under study. With this in mind, the ramp angle of the groove **402** can be selected to match the available shear force q of the beam **102**. If the ramp angle of the groove **402** is too small, the clamp **116** can still provide damping and return the beam **102** to its expected "home" position, but the amount of damping is smaller than when the ramp angle matches the available shear force. If the ramp angle of the groove **402** is too large, the clamp **116** may fail to return the beam **102** to its home position.

FIGS. **5**A and **5**B illustrate an example movement of the roller **212** in the groove **402**. As shown in FIG. **5**A, the roller **212** is approaching the bottom of the groove **402**. Because the clamp **116** is fixed to the beam **102** and the roller **212** is lower within the groove **402**, the roller **212** here applies a smaller amount of downward compression against the underlying beam. As shown in FIG. **5**B, the roller **212** has reached the top of the groove **402** and is beginning to move downward again towards the bottom of the groove **402**. Because the clamp **116** is fixed to the beam **102** and the roller **212** is higher within the groove **402**, the roller **212** here applies a larger amount of downward compression against the underlying beam.

FIG. **6** illustrates example effects that could be achieved using the friction damping clamp **116** on a beam. In FIG. **6**, a line **602** denotes the displacement of a beam's tip after the beam is moved and then released, where the beam lacks a friction damping clamp **116**. A line **604** denotes the displacement of a beam's tip after the beam is moved and then released, where the beam includes a friction damping clamp **116**. As can be seen here, movement of the beam with the friction damping clamp **116** rapidly moves to zero, showing that the friction damping clamp **116** quickly dampens the oscillatory movement of its beam. In contrast, the beam without the friction damping clamp **116** continues with large movements, indicating that a much longer period of time is needed to stop the oscillatory movement of that beam.

As can be seen here, the use of at least one friction damping clamp **116** can rapidly reduce oscillatory movement of a beam or other structure. This can be accomplished in a manner that allows the beam or other structure to return to its desired "home" position. This can also be accomplished without unnecessarily reducing the stiffness of the structure. In addition, this can be accomplished using a much larger percentage of the total damping power that is contained within a beam or other structure.

Although FIGS. **2** through **6** illustrate one example of a friction damping mechanism and related details, various changes may be made to FIGS. **2** through **6**. For example, the sizes, shapes, and relative dimensions of the components in the friction damping clamp **116** are for illustration only and may vary depending on particular circumstances. Also, as noted above, a single roller **212** or multiple rollers **212** could be used with one or multiple grooves **402** to provide friction damping. In addition, the groove **402** could have other shapes and need not be V-shaped. For instance, the groove **402** could have a parabolic shape or a step configuration.

FIGS. **7** through **9** illustrate additional structures with friction damping mechanisms in accordance with this disclosure. As noted above, a three-layer split beam **102** represents one example of the type of beam that could use at least one friction damping clamp **116** to dampen oscillatory movement of the beam. Other types of beams could also be used with the friction damping clamp **116**. For example, FIG. **7** shows a beam **702** used with at least one friction damping clamp **116**. The beam **702** here includes two thicker outer layers and three thinner inner layers. The beam **702** here has twice as many slip/friction planes than in the beam **102**.

FIGS. **8**A through **8**C show a beam **802** used with at least one friction damping clamp **116**, where the beam **802** includes multiple layers **804-808**.

Each layer **804-808** here includes harder outer layers and a softer core layer sandwiched between the harder outer layers.

These layers **804-808** provide increased compliance in compression, and the clamp **116** can be much stiffer than the beam stack when the stack is in compression.

FIG. **9** shows a beam **902** used with a friction damping clamp **116**, where the beam **902** uses a combination of these approaches. Here, the top and bottom sections of the beam **902** include "sandwiched" layers, and the core of the beam **902** is formed from three thinner inner layers. This softens the beam stack's compression stiffness and doubles the number of slip/friction planes compared to the beam **102**.

Although FIGS. **7** through **9** illustrate examples of additional structures with friction damping mechanisms, various changes may be made to FIGS. **7** through **9**. For example, any number of other arrangements of a beam could be used with one or more friction damping clamps **116**. Moreover, as noted above, friction damping clamps **116** can be used with any suitable types of structures and are not limited to use with cantilevered beams or beams in general.

FIGS. **10**A and **10**B illustrate another example friction damping mechanism in accordance with this disclosure. In particular, FIGS. **10**A and **10**B illustrate details of another friction damping clamp **1016**. FIG. **10**A shows a cross-sectional view of the friction damping clamp **1016** taken along a length of a beam **1002**, and FIG. **10**B shows a cross-sectional view of the friction damping clamp **1016** taken along a width of the beam **1002**. The beam **1002** represents a multi-layer beam with three layers, although the beam **1002** could represent any of the beams described above. Also, the friction damping clamp **1016** could be used with structures other than beams, and the beam **1002** or other structure could include any number of friction damping clamps **1016**.

In this example, the friction damping clamp **1016** includes a housing **1050**, which partially encircles the beam **1002**. Note that the housing **1050** could also completely encircle the beam **1002**. The housing **1050** includes at least one groove **1052** defining ramps. The friction damping clamp **1016** also includes at least one roller **1054** and a support structure **1056**, which could contain bearings for the roller(s) **1054** or otherwise support the roller(s) **1054**. The housing **1050** and the support structure **1056** are secured to different layers of the beam **1002** in any suitable manner, such as by using bolts.

The operation of the friction damping clamp **1016** is similar to that of the friction damping clamp **116**, but the relative positions of the roller(s) and groove(s) are reversed. That is, in the friction damping clamp **116**, the groove **402** is located between the roller **212** and the beam **102**. When the roller **212** moves up the groove **402**, the roller **212** causes the housing member **204** to apply more compression to the beam **102**. When the roller **212** moves down the groove **402**, the roller **212** causes the housing member **204** to apply less compression to the beam **102**. Similarly, in the friction damping clamp **1016**, when the roller **1054** moves up the groove **1052**, the roller **1054** causes the support **1056** to apply more compression to the beam **1002**. When the roller **1054** moves down the groove **1052**, the roller **1054** causes the support **1056** to apply less compression to the beam **1002**.

The housing **1050** or the support structure **1056** could be placed at an adjustable distance with respect to the beam **1002**. For example, the height of the support structure **1056** over the top layer of the beam **1002** could be adjustable using the bolts or other connectors coupling the support structure **1056** to the top layer of the beam **1002**. As another example, the height of the housing **1050** over the top layer of the beam **1002** could be adjustable using the bolts or other connectors coupling the support structure **1056** to the bottom layer of the beam **1002**. Again, this allows for the tuning of the friction force applied to the beam **1002**.

Note that the directions "up" and "down" are reversed in the friction damping clamps **116** and **1016**. In this document, the term "up" (when used with respect to a roller's movement on a ramp of a groove) refers to movement of the roller away from a home position of the roller. Similarly, the term "down" (when used with respect to a roller's movement on a ramp of a groove) refers to movement of the roller towards the home position of the roller. The "home position" of the roller represents the position of the roller in the groove where the roller applies a minimal or no amount of compression to a structure.

Although FIGS. **10**A and **10**B illustrate another example of a friction damping mechanism, various changes may be made to FIGS. **10**A and **10**B. For example, the sizes, shapes, and relative dimensions of the components in the friction damping clamp **1016** are for illustration only and may vary depending on particular circumstances. Also, a single roller **1054** or multiple rollers **1054** could be used with one or multiple grooves **1052** to provide friction damping. In addition, the groove **1052** could have other shapes and need not be V-shaped. For instance, the groove **1054** could have a parabolic shape or a step configuration.

FIG. **11** illustrates an example method **1100** of using a friction damping mechanism in accordance with this disclosure. The method **1100** is described with respect to the multi-layer beam **102** operating in conjunction with the friction damping clamp **116**. The method **1100** could be used with any other suitable structure having any number of friction damping clamps. The method **1100** could also be used with any other suitable friction damping clamp(s), such as the one shown in FIGS. **10**A and **10**B.

As shown in FIG. **11**, a beam resides substantially in its "home" position at step **1102**, and at least one roller in a friction damping clamp resides substantially in the center of at least one groove at step **1104**. This could include, for example, the end of the beam **102** residing in a known location and the roller(s) **212** of the friction damping clamp **116** residing at the center of the groove(s) **402**. In this position, the beam is not experiencing displacement.

The beam begins to undergo oscillatory movement at step **1106**. This could include, for example, the end of the beam **102** being displaced and then released, causing the end of the beam **102** to oscillate back and forth. Oscillatory movement of the beam **102** could be created in any other manner. During this time, the at least one roller in the clamp travels up and down the ramps of the at least one groove at step **1108**. This could include, for example, each roller **212** moving up and back down the ramp on one side of its groove **402** and then moving up and back down the ramp on another side of its groove **402**. This can occur repeatedly until the beam stops moving. As a result of the movement of the roller(s) up and down the ramps of the groove(s), the clamp provides variable friction to the layers of the beam at step **1110**. This could include, for example, the clamp **116** creating more friction between the beam layers when each roller **212** is higher on a ramp in its groove **402**. This could also include the clamp **116** creating less friction between the beam layers when each roller **212** is lower on a ramp in its groove **402**.

Eventually, the beam comes to a rest again substantially in its "home" position at step **1112**, and the at least one roller resides substantially in the center of the at least one groove at step **1114**. Here, the friction between the layers of the beam **102** causes the beam **102** to come to rest, and the reduced friction present when each roller **212** is located in the center of its corresponding groove **402** causes the beam **102** to stop substantially at its "home" position.

Although FIG. **11** illustrates one example of a method **1100** of using a friction damping mechanism, various changes may be made to FIG. **11**. For example, while shown as a series of steps, various steps in FIG. **11** could overlap, occur in parallel, or occur any number of times. As particular examples, steps **1102**-**1104** can overlap, steps **1106**-**1111** can overlap, and steps **1112**-**1114** can overlap.

Note that in the above description, it has been assumed that each groove **402** is symmetrical. However, this need not be the case, as the ramp on one side of a groove **402** could have a different slope that the ramp on another side of the groove **402**. This would affect how oscillatory movement of a structure is suppressed, but it may still be acceptable in various circumstances.

It may be advantageous to set forth definitions of certain words and phrases used throughout this patent document. The terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation. The term "or" is inclusive, meaning and/or. The phrase "associated with," as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like. The phrase "at least one of," when used with a list of items, means that different combinations of one or more of the listed items may be used, and only one item in the list may be needed. For example, "at least one of: A, B, and C" includes any of the following combinations:

A, B, C, A and B, A and C, B and C, and A and B and C.

While this disclosure has described certain embodiments and generally associated methods, alterations and permutations of these embodiments and methods will be apparent to those skilled in the art. Accordingly, the above description of example embodiments does not define or constrain this disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of this disclosure, as defined by the following claims.

What is claimed is:

1. A system comprising:
- a structure configured to undergo oscillatory movement, the structure comprising a beam, at least part of the beam comprising multiple layers that define multiple slip/friction planes within the beam; and
- a friction damping clamp coupled to the structure and at least partially wrapping around the beam, the friction damping clamp comprising:
  - a housing having a groove; and
  - a roller positioned at least partially within the groove, the groove having first and second ramps;
- wherein the roller is configured to cause increased compression to at least one of the layers of the beam by moving up each ramp of the groove; and
- wherein the roller is also configured to cause reduced compression to at least one of the layers of the beam by moving down each ramp of the groove.

2. The system of claim **1**, wherein:
- the roller is configured to cause increased compression to at least one of the layers of the beam in order to increase friction between the multiple layers of the beam; and
- the roller is configured to cause reduced compression to at least one of the layers of the beam in order to decrease friction between the multiple layers of the beam.

3. The system of claim **2**, wherein the roller is configured to cause substantially no compression on the beam when the roller is located at a center of the groove.

4. The system of claim **3**, wherein the friction damping clamp is configured to cause the structure to return to substantially a same position after each displacement of the structure.

5. The system of claim **1**, wherein multiple friction damping clamps are coupled to the structure.

6. The system of claim **1**, further comprising:
- one or more anti-buckling rollers positioned along the structure and configured to prevent buckling of the structure.

7. The system of claim **1**, wherein at least one of the groove and the roller has an adjustable position with respect to the structure.

8. The system of claim **1**, wherein at least two of the layers have different thicknesses.

9. The system of claim **1**, wherein the multiple layers include two harder outer layers and a softer inner layer sandwiched between the outer layers.

10. The system of claim **1**, wherein the groove comprises a V-shaped groove.

11. An apparatus comprising:
- a friction damping clamp configured to be coupled to a structure that undergoes oscillatory movement, the structure comprising a beam, at least part of the beam comprising multiple layers that define multiple slip/friction planes within the beam, the friction damping clamp configured to at least partially wrap around the beam, the friction damping clamp comprising:
  - a housing having a groove; and
  - a roller positioned at least partially within the groove, the groove having first and second ramps;
- wherein the roller is configured to cause increased compression to at least one of the layers of the beam by moving up each ramp of the groove; and
- wherein the roller is also configured to cause reduced compression to at least one of the layers of the beam by moving down each ramp of the groove.

12. The apparatus of claim **11**, wherein:
- the roller is configured to cause increased compression to at least one of the layers of the beam in order to increase friction between the multiple layers of the beam; and
- the roller is configured to cause reduced compression to at least one of the layers of the beam in order to decrease friction between the multiple layers of the beam.

13. The apparatus of claim **12**, wherein the roller is configured to cause substantially no compression on the beam when the roller is located at a center of the groove.

14. The apparatus of claim **13**, wherein the friction damping clamp is configured to cause the structure to return to substantially a same position after each displacement of the structure.

15. The apparatus of claim **11**, wherein the housing comprises:
- a first housing element configured to be coupled to one part of the structure; and
- a second housing element configured to be coupled to another part of the structure, the second housing element having the groove;
- wherein the roller is configured to cause the first housing element to compress the structure.

16. The apparatus of claim **11**, wherein:
- the housing is configured to be coupled to one part of the structure;
- the friction damping clamp further comprises a support structure configured to couple the roller to another part of the structure; and

the roller is configured to cause the support structure to compress the structure.

17. The apparatus of claim **11**, wherein the friction damping clamp comprises multiple rollers, the rollers positioned at least partially within one or more grooves in the housing.

18. A method comprising:

creating oscillatory movement of a structure, the structure comprising a beam, at least part of the beam comprising multiple layers that define multiple slip/friction planes within the beam; and

damping the oscillatory movement using a friction damping clamp coupled to the structure, wherein the friction damping clamp at least partially wraps around the beam, wherein the friction damping clamp comprises:

a housing having a groove; and

a roller positioned at least partially within the groove, the groove having first and second ramps;

wherein damping the oscillatory movement comprises:

moving the roller up each ramp of the groove to cause increased compression to at least one of the layers of the beam; and

moving the roller down each ramp of the groove to cause reduced compression to at least one of the layers of the beam.

19. The method of claim **18**, wherein:

the roller causes increased compression to at least one of the layers of the beam in order to increase friction between the multiple layers of the beam; and

the roller cause reduced compression to at least one of the layers of the beam in order to decrease friction between the multiple layers of the beam.

20. The method of claim **19**, wherein the roller causes substantially no compression on the beam when the roller is located at a center of the groove.

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